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Abstract for A Study of the Efficiency of Biodiesel Reactors

The following paper attempts to settle the question of how to build the most efficient Appleseed, the most common type of homemade Biodiesel reactor. Through a variety of primary and secondary research, I tried to determine why there are great discrepancies about the best approach to build an Appleseed. I begin my paper with a description of what both Biodiesel and the Appleseed are, and why they are important to our future and sustainability. I outline exactly what is needed to build an Appleseed: which parts are best to use, how to properly wire it, what type of pump to buy, how to make it safe, how to make Biodiesel in it, etc... I also outline what I did to build the Appleseed which I believe is most efficient and why I believe my model is successful. After reading my paper, you should be familiar with all the sections of an Appleseed as well as which parts maximize efficiency, how to design an efficient system, and perhaps most importantly, why one system is better than another and why it is important to maximize the efficiency of an Appleseed.

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A Study of the Efficiency of Biodiesel Reactors

In the age of alternative energy, there are many competitors vying to become the replacement for gasoline and petroleum products. While it remains unclear which option will become the next standard, one source of energy gaining ground is Biodiesel fuel. Biodiesel is a renewable, carbon neutral fuel, which can be made from any source of feed oil (National Biodiesel Board). Biodiesel is less toxic than table salt and more biodegradable than sugar (William Kemp). It operates on a closed carbon cycle and reduces Carbon Dioxide by 2.2 kilograms, or 78% for every liter of fossil fuel it displaces (Kemp). According to the American Society for Testing and Materials (ASTM) Biodiesel is defined as a fuel comprised of the "mono-alkyl esters of fatty acids derived from vegetable oils or animal fats" (National Biodiesel Board). At the heart of the Biodiesel movement is the local producer. The local producer makes Biodiesel at home, usually using a homemade reactor.

The most popular type of homemade processor is the Appleseed. The Appleseed is a water heater based processor invented by Maria Alover (make-biodiesel.org). Although the Appleseed of today is slightly different than the original design, it still contains the original design criteria: no welding, readily available parts, and improved safety compared to other available methods (make-biodiesel.org). Equally important, an Appleseed can be built in one day for between \$400-\$800. All of those aspects cemented

the Appleseed as the standard for home brewers.

One question that remains about the Appleseed is how to increase the efficiency of the processor. The efficiency of a processor can be defined by the following: cost to build; cost to produce fuel; how easy is it to build; how easy it is to operate; energy efficiency; best quality fuel; most environmentally friendly; and safest. Furthermore, the most efficient Biodiesel processor is one that combines ease of use, cost efficiency, and safety, yet still produces a high quality fuel without harming the environment.

Basic Information

The first question that arises when trying to build the most efficient Biodiesel processor is which basic model is most efficient. The answer is the Appleseed processor. The advantages of the Appleseed processor are its simple design and the availability of water heaters (Guy Purcella). The Appleseed processor is simple, cheap, and safe (Jon Starbuck). When making Biodiesel in an Appleseed, the reaction occurs in the water heater. The oil is heated and processed in the heater while the Methoxide is mixed in a separate carboy (Purcella). Then, the Methoxide is added to the water heater and the transesterification occurs (Starbuck). The fuel that results from the transesterification is Biodiesel, or Fatty Acid Methyl Ester (FAME).

Biodiesel has a higher centane value than petroleum diesel. That means that when Biodiesel is burned in an engine, it has a smoother and more complete ignition (Kemp). This results in improved combustion and less unburnt fuel (Kemp). In addition, the FAME molecule contains 11% more oxygen than regular gasoline which reduces both soot and sulfur (Kemp). The downsides to using Biodiesel are that when exposed to ,high

temperatures, excess oxygen, or sunlight, the Biodiesel can deteriorate and thicken, which can plug the fuel filter (Kemp). Biodiesel is also very hygroscopic and water can lead to bacteria growth. The problem can however, be corrected with chemicals which kill the bacteria and prevent new growth (Kemp). In order to prevent bacteria growth and ensure that your biodiesel meets ASTM Standard D6751 for Biodiesel, it is important to test the quality of your fuel (Graydon Blair Interview).

Besides its simplicity, an advantage of the Appleseed is that it can consistently deliver Biodiesel that meets ASTM standards. The simplicity of the design is such that even people building their first Appleseeds seem to have little trouble. Biodiesel expert Graydon Blair, president of Utahbiodieselsupply.com, says that he didn't find it difficult to build his first Appleseed (Graydon Blair Interview). Rick Boggan, head of make-biodiesel.org, agrees with Graydon, saying that he too did not find it difficult to build an Appleseed. He just found some plans on the Internet and followed them (Rick Boggan Interview). Appleseed Plans are readily available on the Internet thanks to the open-source philosophy of inventor Alovert. After popularizing her design on nationwide tours, Alovert used the Internet to improve her design (make-biodiesel.org). Alovert used Internet Forums to engage a large number of volunteers to improve and test her design (make-biodiesel.org). What resulted from Alovert's efforts is the Appleseed of today. Adopted as a safe and reliable standard, it is the lowest cost design available and the processor of choice for many Biodiesel enthusiasts (make-biodiesel.org).

Basic Appleseed Design

The Appleseed of choice for many local producers comes in a kit. In fact there are many great Appleseed kits available all over the Internet. Before buying an Appleseed kit, be sure to consider if the kit has all the necessary parts. If it does not, it should clearly indicate which parts you will need to buy yourself (Purcella). Graydon Blair says that using a pre-made kit is very helpful (Graydon Blair Interview). His website offers a kit that comes with everything, including plans and easy to use instructions that explain exactly how to put the Appleseed together (Graydon Interview). Blair also says that using standardized plans is helpful when building an Appleseed.

If you decide that you want to build your own Appleseed rather than using a kit, be sure to consider the following. All a Biodiesel processor needs to be able to do is filter the oil, dewater the oil, heat it to 130 degrees Fahrenheit, dissolve and evenly integrate the catalyst, and mix the oil while the reaction occurs, and separate the glycerol and other by-products (Starbuck). So when designing your own processor you have to consider how the oil will be heated and from how long (Purcella). When thinking about heating, you also have to consider temperature monitoring and regulation. If the Biodiesel is too hot, the Methanol can boil and you run the risk of an explosion. But if it is too cold, the reaction takes too long and it is inefficient. Another thing to consider is tank venting; without proper ventilation, you run the risk of killing yourself from inhaling methanol vapors (Purcella). You also have to be sure that the pump you use is powerful enough. If you use an inadequate pump than the catalyst will not fully integrate with the oil and it will lead to an incomplete reaction (Purcella).

Both Graydon Blair and Rick Boggan have extensive experience with Appleseed Processors and have each designed a personal version of the Appleseed. In late 2004,

Blair finished tweaking his personal design and came up with the version that his company now sells in a kit. Blair said he was initially impressed with the simplicity of the design, the ease of assembly, and the safety features the set-up offered (Graydon Blair Interview). Rick Boggan says that the most important thing to consider when designing an Appleseed is figuring out how each part will fit into the whole system. He says when designing an Appleseed, do not design a component, design a whole system. When Boggan makes customizations to the Appleseed Design, he focuses on improving system integration. Boggan also says that most people focus too much on individual components rather than on the system as a whole. Design everything to work together, Boggan advises (Rick Boggan Interview).

Water Heater

The Water Heater is one of the most important parts of any Appleseed. The water heater has to heat the oil as well as hold it during the actual reaction. Not surprisingly, some types of water heaters are better than others. While the ideal material water heater for an Appleseed is stainless steel, it is usually so expensive that it is not justifiable economically (Starbuck). In fact, stainless steel is usually ten to twenty times as expensive as a stainless tank (Purcella). Besides stainless steel, a plain steel tank will also work well as will Medium Density Polyethylene. However, you want to avoid using a galvanized water heater (Purcella). When shopping for a water heater, you want to buy the cheapest one available in the size you want because often times more expensive ones will have unnecessary features, like electronic controls which make wiring harder (make-biodiesel.org). The only requirements for the water heater are that it is electric, has hot

and cold water inlets on the top of the tank, and has the screw-in type heating elements (make-biodiesel.org).

Using a basic water heater has several advantages: it already has all of the inlet and outlet ports, heating elements, and thermostat (Purcella). For the Biodiesel beginner, a 40 or 60 gallon tank is ideal. The 40 gallon tank is the least expensive and most commonly found (make-biodiesel.org). The smaller models are cheaper and more economical for the small scale producer (New Appleseed Design Infopop). In addition, the 40 and 60 gallon tanks are low cost, energy efficient, and have a self-draining conical bottom (Kemp). With a 40 gallon tank, you can make up to 25 gallons of Biodiesel in one batch (make-biodiesel.org). There are two basic designs for water heaters, the tall and skinny version and the shorter and fatter version. Each version has its own advantages. The tall and skinny water heaters tend to accumulate less biodiesel in the glycerin because the drain is on the side (New Appleseed Design Infopop). The short fat tank is much more stable, and it is easier to mix the methoxide in the wider tank (make-biodiesel.org).

Some people choose to make their Appleseed with a used water heater, and while this will work, it is much easier to start with a new one (make-biodiesel.org). Using a used water heater will save you hundreds of dollars, but there are several things you must do to it first (make-biodiesel.org). First, you have to clean and unseize the plumbing, which will often take a day or two. You also can never be certain that a used water heater will not leak until you test it out. Lastly, used heaters will often have rust on the heating elements, in which case it can not be used (make-biodiesel.org). Graydon Blair says to always use a new water heater, as "old ones work, but can have leaks, rust, or calcium deposits. [They] are a pain to work with." (Graydon Blair Interview). Blair prefers to use

the new GE brand water heaters from Home Depot because they are easy to work with and all the ports are in the right place (Graydon Blair Interview). Rick Boggan uses a new 40 gallon tank in his Appleseed design so he can make Biodiesel in 20-25 gallon batches (New Appleseed Design Infopop).

Once you have selected your water heater, you have to make certain modifications, regardless of whether it is new or old, before you can use it to make biodiesel. Since the tank is not going to be completely filled, the upper heating element must be removed, otherwise it will burn out the first time it is turned on (Kemp). You also have to remove the sacrificial anode and cap it to prevent metals getting into the Biodiesel (Kemp).

Plumbing

When it comes to plumbing for an Appleseed, the standard material is black pipe. It has both threaded ends and receptors, comes with a standard diameter, and is available in incremental lengths for custom designs (Kemp). The black steel pipe is plentiful, cheap, and easy to work with (Run Your Diesel Vehicle on Biofuels). The ends of the pipe have to be taped, preferably with Teflon tape, to ensure a tight, leak-proof seal (Purcella). Caps, 90 degree elbows, valves, and other fittings are available in black pipe (Kemp). Another advantage of using steel pipe is that it with stands the heat better than other options (Graydon Blair Interview). Be sure to avoid using galvanized metal, copper pipe, brass regulators, or copper fittings as it will react with the Biodiesel (Purcella).

While black steel pipe is certainly the best option for the majority of the plumbing, some connections, like the sight tube, should be made from clear, reinforced, braided flexible plastic pipe (Kemp). Liquid sensors are too expensive for the home brewer, but

with clear plastic pipes liquid levels can be checked with a glance (Kemp). Plastic will degrade with time, heat, and chemicals, so it is necessary to replace the sight tube every year (Kemp). Expert William Kemp, author of *Biodiesel Basics and Beyond*, uses basic clear braided plastic for his sight glass (Kemp). Rick Boggan says to make the sight tube out of Teflon so that it can withstand the chemicals and heat without leaking or weeping (Rick Boggan Interview). When buying hoses for the sight tube, always purchase reinforced hoses as non-reinforced will rupture. Also, thick-wall hoses are always better than thin-wall (Purcella). In his new Appleseed design, Boggan uses a 3/8 inch sight tube made from polyethylene rather than PVC for improved chemical resistance (New Appleseed Design Infopop).

The ball valves for an Appleseed should be made from either brass or stainless steel. PVC is simply too weak (Purcella). If buying brass valves, make sure that the balls inside are made of metal and not metal plated plastic (make-biodiesel.org). Graydon Blair says to be sure to install the ball valves so that when they are open, they point in the direction of the flow of oil. That way it is easy to identify both when a valve is open and which way the oil will flow (Graydon Blair Interview). Rick Boggan says that when designing an Appleseed, be sure to make sure that all of the valves are reachable so that they can be opened and close easily (Rick Boggan Interview).

Graydon Blair says that the plumbing was the main challenge for him when building his first Appleseed. Back then, he says, there was no standard, so he had to guess. The first time he used that Appleseed, glycerin settled in the pipes and gelled, so he had to redesign the plumbing to ensure that it drained totally (Graydon Blair Interview). Blair also says to replace, if possible, the PVC tube that extends from the pump to the

processor with metal pipe because the tube can be a point of failure (Graydon Blair Interview). Boggan takes Blair's advice, using all steel plumbing in the circulation loop as well as a plumbed drain and return on the bottom.

Wiring

Wiring is one of the most dangerous parts about building an Appleseed. Every Biodiesel expert and resource strongly recommends consulting with an electrician before trying to wire an Appleseed. Since the water heater is not going to be completely filled, the upper heating element must be disabled so it does not burn out the first time the machine is turned on. The upper thermostat also contains the thermal protection switch (make-biodiesel.org) You will use the lower thermostat and heating element without making any modifications. After the upper thermostat is disabled, you will rewire the switch to give redundant thermostatic protection (make-biodiesel.org). In order to disable the upper thermostat, the two wires connected to the thermostat must be completely removed (make-biodiesel.org). You should however, leave the actual upper heating element in place to use as a potential spare in case the lower one burns out. The point of making the wiring modifications is to introduce redundancy into the thermostats. That way if one element fails, the other will shut everything down if the temperature rises beyond its set point, usually 140 degrees (make-biodiesel.org).

When connecting the Appleseed to the junction boxes, it is necessary to use Ground fault circuit interrupters (GFCI). They are required any time water and electricity are in the same system. The easiest way to do that is to use either a GFCI adapter or a GFCI extension chord. They plug into existing outlets and offer GFCI protection for up to 15

amps per device (make-biodiesel.org). When it comes to actually heating the oil, most people use 110V because it is what is available near the processor. But, by using 240V, you can heat the oil up to four times faster. Caution must be taken though, because it will burn out the heating element if you forget to run the pump while you heat the oil (make-biodiesel.org). This is because oil transfers heat away from the heating element slower than water, which can lead to the heating building up in the element and the element burning out (make-biodiesel.org). The primary cause of burnt out heating elements is dirty oil; particles from the oil stick to the element and insulate it, preventing heat transfer (make-biodiesel.org) You can avoid early burn outs by using a 240V low watt density heating element (make-biodiesel.org).

The other important thing about wiring is the thermometer. Having a good thermometer is essential not only because if the oil over heats it can become a safety risk, but also because by properly monitoring the temperature, you can reduce your energy costs and increase your efficiency. William Kemp recommends using a digital thermometer that can go up to at least 175 degrees Fahrenheit (Kemp). The thermometer should be placed firmly between the tank wall and the insulation to ensure a tight fit (Kemp). Because old thermostats stick, be sure to use a new thermostat, even if you are using a used heater. Also, be sure to replace your thermostat at least once a year (make-biodiesel.org). In his new Appleseed design, Rick Boggan uses a bi-metallic thermometer placed at the TNP port (New Appleseed Design Infopop).

There are a few other things to consider when it comes to wiring an Appleseed. While these things are not essential, adding them will improve both safety and efficiency. By putting the heating element on a separate circuit in its own service panel with its own

breaker, you can improve the safety features of the Appleseed (Purcella). Graydon Blair recommends installing electric timers to make the wiring safer. That way if something is accidentally left unattended, it will shut itself off (Graydon Blair Interview). Blair also wires a junction box with light switches and always uses high quality, heavy duty 10-gauge wire to ensure that the wiring is electrically sound (Graydon Blair Interview). When wiring an Appleseed, be sure to watch the total load on all of the wires to make sure that you are not tripping breakers and melting extension chords (make-biodiesel.org).

Pump

According to the Biodiesel experts at Infopop, it is entirely possible to make Biodiesel in a cheap tank, as long as you have a good pump. The inverse is not however, possible (Appleseed Efficiency Infopop). This means of course that in order to make high quality Biodiesel, you need a high quality pump. The most common pumps are the Harbor Freight and the Northern Industrials Clearwater (make-biodiesel.org). While most people use the inexpensive Harbor Freight brand clear water pump, its flow rate is inadequate (Purcella). Graydon Blair says the Harbor Freight pumps are junk and should be avoided (Graydon Blair Interview). The Harbor Freight pump uses an undersized capacitor which breaks easily. It has also been known to leak from several places (make-biodiesel.org). When purchasing pump, you need to buy one with a flow rate of at least ten gallons per minute. You also want to make sure that the pump is totally enclosed, fan cooled, and rated for higher temperature fluids and mild to medium corrosives (Purcella). It is also important to buy a spark proof pump to reduce the risk of fire (Starbuck).

The other pump that people use besides the Harbor Freight is the one from Northern Industrial. The Northern Industrial pump has a flow rate that is twice as fast as the Harbor Freight. This means that the catalyst can be mixed faster, the oil can be transferred faster, and that it will be easier to prime (Purcella). Another advantage of the Northern Industrial pump is that the fan is bolted into place so it will not become misaligned and break the motor, as can happen with the Harbor Freight pump (make-biodiesel.org). Graydon Blair says to either use the Northern Industrial Clearwater pump or a pump from murphysmachines.com (Graydon Blair Interview).

Once you have selected your pump, there are a few modifications you can make to make your pump safer. The first thing that you can do is add a six to ten amp slow blow fuse wire in-line. Adding the slow blow fuse wire will help protect against a locked motor (make-biodiesel.org). For thermal protection, the best option is to use a manual motor starter. The manual starter has thermal overload protection built in and can also be used as an on-off switch (make-biodiesel.org).

Safety

This next section is perhaps the most important of this entire paper. After all, what is the point of trying to make Biodiesel if you are going to get injured or killed doing it. Making Biodiesel involves toxic dangerous chemicals, hot oil and water, and electricity. Without a serious investment in safety, it is too easy to be seriously injured. In fact, Graydon Blair says that safety is the most important thing to consider when designing an Appleseed (Graydon Blair Interview). He also says that anything you can do to make a design safer is an improvement (Graydon Blair Interview). **When it comes to safety,**

prevention is always the lowest cost and lowest risk way to be safe (Kemp).

It is essential to have system grounding for all of the electrical work. That way excess electricity has a safe route to dissipate through in case of a fault condition (Kemp). It is also important to make use that the room in which the Biodiesel is made is properly ventilated to the outdoors (Graydon Blair Interview). Blair also says to always wear the proper safety gear, especially when handling chemicals (Graydon Blair Interview). Once you have addressed all of those issues, it is time to turn to the biggest safety issue of an Appleseed, the heating element.

The biggest safety risk of an Appleseed is leaving the heating element on. In the original Appleseed design, if the heating element is left on, the Biodiesel will catch on fire inside the tank when it is time to drain it (Rick Boggan Interview). Since a hot heating element can also ignite methanol vapors, you should make it extremely difficult to turn on the element when the processor is empty (Graydon Blair Interview). If necessary, you should install some sort of device that will prevent you from turning on the element when the tank is empty, like a timer or switch (Graydon Blair Interview). You should also always unplug the processor in between batches (make-biodiesel.org). As long as you take those precautions against dry fires, you should be able to safely make Biodiesel in your Appleseed.

Some of the advantages of the Appleseed design are the built-in safety features of the hot water heater. All hot water heaters are pressure rated to 300 psi, have built-in insulation, come pre-wired, and do not require any welding (Graydon Blair Interview). Still, there are other things you can do to prevent accidents. Blair recommends building a large frame cart with wheels. That way, not only is everything contained and movable,

the risk that the processor tips over is greatly reduced. Also, while some producers recover the methanol in a condenser to reduce costs and make their set-up more "green", Rick Boggan recommends against methanol recovery, saying "alcohols have a long history of blowing up and killing people, I'd rather waste a few dollars than risk an explosion" (Rick Boggan Interview). It is also important to have secondary containment of spills for safe and environmentally friendly Biodiesel (Rick Boggan Interview). Lastly, hard plumbing the connections between the processor and wash tank, rather than using PVC, will avoid pressure build up from leaving the pump on (make-biodiesel.org).

While it is clear that Appleseeds offer a relatively safe way to make Biodiesel, there are still some members of the Biodiesel community who do not use them. Even with both the built-in safety features that water heater offers and the features you can add, some people refuse to use the Appleseed because of the electric heating element. Dr. Jon Van Gerpen, department head at the University of Idaho, says that the problem with the Appleseed is that it retains an electric heating element, which makes it an explosion hazard (Jon Van Gerpen Interview). Van Gerpen says that if someone forgets to turn off the heating element, after the Biodiesel and Glycerin are drained, the heater can get hot enough to potentially ignite the methanol-air mixture, causing the tank to explode (Jon Van Gerpen Interview). Van Gerpen believes that Biodiesel reaction systems should be explosion proof, which usually means no electric heat. If he could change one thing about the Appleseed, he "would eliminate electric heat" replacing it some type of external heating system (Jon Van Gerpen Interview). Despite Van Gerpen's warnings, I believe that as long as the proper precautions are taken to ensure that the heating element is never left on, it is perfectly possible to make safe Biodiesel in an Appleseed.

Extra Features

While the previous sections have focused on the essential features of an Appleseed, this section focuses on features of an Appleseed that, while not absolutely necessary, make Biodiesel production more efficient. Some features reduce the cost of energy, others make the process more environmentally friendly, and others make the process safer. All of the features help make using an Appleseed easier. One of the easiest yet most helpful extra features for an Appleseed is building a stand for it to rest upon (Graydon Blair Interview). Both Graydon Blair and Rick Boggan agree that building a stand for an Appleseed will make it much easier to operate. In his new Appleseed Design, Boggan uses a steel stand rather than wood (Rick Boggan Interview).

Another helpful feature is adding a control panel with switches and timers. Blair likes to add both float level switches and timers to all of his Appleseeds (Graydon Blair Interview). Boggan also uses a float switch and a complex control panel in his design (Rick Boggan Interview). When making a control panel, you should focus on safety and automation (make-biodiesel.org). By installing a toggle switch on the control panel to power the pump, you can prevent confusion over which switch turns on the heating element (make-biodiesel.org). Adding a spring wound timer can greatly reduce the risk of dry fire by shutting of the heating element (make-biodiesel.org).

When it comes to adding extra features in an Appleseed, the king is William Kemp. In his Biodiesel lab, he has a four tank set-up and runs a completely self-sufficient, environmentally friendly system. He even powers his lab with a diesel generator that runs on the Biodiesel he makes (Kemp). Kemp also uses a methanol reactor to recover excess

methanol and clean his glycerin. He then, either composts, or makes soap with his purified glycerin (Kemp). He also cleans and reuses his waste water, meaning his system has no waste stream (Kemp). While most producers do not use nearly as many features as Kemp, he still has advice for them: install an optional heat control switch. Adding the heat control can greatly reduce energy costs (Kemp). While each of those extra features helps to make Biodiesel more environmentally friendly, perhaps the ultimate environmental move is heating the oil with solar radiant heat, which some producers do (Graydon Blair Interview). Regardless of which features you install in your Appleseed, they will all help to make your Biodiesel production more efficient.

Making Biodiesel in an Appleseed

Once you have successfully built an efficient Appleseed, you can begin to make Biodiesel in it. After all, the point of designing and building an Appleseed is to make Biodiesel. The basic formula for Biodiesel is 100kg Waste Vegetable Oil (WVO) + 10kg Methanol = 100kg Biodiesel + 10kg of glycerol (Kemp). You should use a volume of methanol equal to twenty percent of the volume of WVO, meaning for 20 gallons of WVO you should use 4 gallons of methanol (Kemp). In order to get the best reaction results, the oil should stay between 120-130 degrees Fahrenheit (Purcella). This means that if your oil drops below 120 degrees, you have to add more insulation to your Appleseed.

Once the oil is added and brought up to the correct temperature, it is time to do a titration. A titration is what you do to determine the amount of catalyst that is necessary to neutralize the free-fatty-acids (Purcella). After the titration, you mix the methanol and

catalyst, either Potassium Hydroxide or Sodium Hydroxide, and add it to the Appleseed. Once the methanol is added you should not use the heating element as methanol is extremely flammable. The methanol should be added slowly and once it is, the oil should be circulated using the pump for 2-3 hours (Purcella). Once the circulation is finished, you have to let the Biodiesel settle and drain the glycerol. At this point, you have raw Biodiesel. Before it can be used however, it must be washed and dried to refine it.

While the basic method outline above will produce Biodiesel that meets ASTM standard D6751 for Biodiesel, the 80/20 method has been shown to improve the reaction rate. The 80/20 method is supported by the University of Idaho, one of the leaders in Biodiesel research (Purcella). It starts out the same as the original, except when it comes time to add the methoxide, you only add 80%. Then you circulate the oil for two hours, after which you wait for the glycerol to drop and drain it. It usually takes about 30 minutes (Purcella). Once the glycerol has been gained, you add the remaining 20% of the methoxide and process for three hours before finishing the process in the same way as the original method (Purcella).

Once the WVO has finished reacting in the Appleseed and the glycerol has been drained and properly stored, the raw Biodiesel must be washed. This is because at this stage in the reaction, the Biodiesel still contains soaps and excess catalyst (Starbuck). By washing the Biodiesel with water, you remove theses soaps and catalysts. Finally, the Biodiesel must be dried and filtered down to 10 microns before it can be used (Starbuck).

My Appleseed

This next section will cover what I did to build and make fuel with my Appleseed. In this section, you will see exactly what I did to build the most efficient Appleseed possible and why I choose to use each part. One thing I had to consider when designing and building my Appleseed was how it would fit into the systems that Greengineering already has in place. Since I would not only be leaving my Appleseed with Greengineering but also making fuel in their lab, I had an incentive to make my design fit in smoothly with their systems. That meant I had to consider things like how my design would fit in with their methanol condenser and how to best move my fuel to their wash tanks.

I choose to use a 50 gallon GE tank that I got from home depot for \$279.90 with a ten percent discount. With the 50 gallon tank, I can make up to 35 gallons of Biodiesel per batch. The original plan was to use an 80 gallon water tank to make Biodiesel in 50 gallon batches, however, the 50 gallon tank and 35 gallon batches proved to be the most efficient for a variety of reasons. The 80 gallon tank posed two major problems. First, the Clearwater pump is not large enough to handle making the 50 gallon batches and the pumps that are large enough are very expensive. The other problem was that a 50 gallon batch would require two separate wash cycles because neither wash tank is large enough. On the other hand, with the 50 gallon water heater, I can make 35 gallon batches which can be washed in either the Bio Pro 150 that Greengineering has or their barrel wash tank. Clearly, the 50 gallon water heater was the most efficient choice.

I choose to plumb my Appleseed with Black Steel Pipe. Not only is it one of the best options for the plumbing parts, but the Greengineers had an abundance of extra Black Steel parts, making it by far the most economical choice. Furthermore, I will be able to

use the money I save from not having to buy plumbing parts to upgrade other features of my Appleseed. In order to try to make the machine more efficient, I chose to hard plumb the connection between the pump and the water heater. I made the site tube on a separate location that I can open and close with a ball valve. That way, I can close the site tube when running the machine in order to conserve heat. I also decided to plumb one port to drain the Biodiesel and Glycerin and a different port to add the Methoxide and Waste Vegetable Oil.

When designing the plumbing system, I tried to keep in mind Occam's razor, meaning I tried to keep the design as simple as possible. By keeping the plumbing design simple, I made it easy to assemble and even easier to operate. I designed all of the ball valves to point in the direction of the flow of oil when open. Also by keeping the plumbing design simple, I minimize the distance the oil circulates. Therefore, the amount of heat lost during the circulation is minimized. And since the majority of the energy used in production comes from heating the oil, by keeping the plumbing simple, I have made the Appleseed more energy efficient by reducing the heat lost. I believe my plumbing design offers a simple yet effective way to circulate the oil as well as add and drain off the necessary components.

Although I thought that wiring the Appleseed would be my biggest challenge, it actually proved to be much simpler than I anticipated. Like every expert said, I was able to use the lower heating element without making any wiring modifications. I simply had to adjust the thermostat so it would go up to 140 degrees. On the upper heating element, I had to rewire it so that it would bypass the element. While I expected this to be complicated, in reality it was simple. All it required was disconnecting the wires from the

heating element and reattaching it to the other side. At the recommendation of utahbiodieselsupply.com, I am using 12 and 14 gauge cord to connect the pump and water heater to the main circuit. I will be connecting them with a power outlet with a timer and 20 amp GFCI protection. I also decided to use a digital thermometer to measure the temperature. Overall, wiring my Appleseed was not nearly as complicated as I thought it would be.

I chose to use the Northern Industrials Clearwater pump for my Appleseed. After all of my research, it was clear that the Clearwater pump was the best choice. The pump cost \$50.00 yet is well made and able to thoroughly integrate the catalyst. The Clearwater pump offers a flow rate of 720 gallons per hour, more than what is required. The Clearwater pump also fits in well with my plumbing design. Choosing a pump was not a difficult choice; the Harbor Freight pump is junk and almost every other option was way too expensive. The Clearwater pump offers a choice that is powerful enough to mix the oil and catalyst, yet still affordable.

In my opinion and that of almost every Biodiesel expert, safety is the most important thing to consider when designing, building, and running an Appleseed. In that line of thought, I included numerous features to make sure that my Appleseed is safe. First, I chose to use GFCI adaptors. In order to address the most important problem, leaving the heating element on, I did several things. I connected the heating element to a timer so that it will shut off on its own. I also have a back up timer in case the first one fails. I also plan to always unplug the heating element when it is not in use as an extra precaution. I also decided to hard plumb the connection between the pump and processor to avoid using PVC, which can fail. I believe that with all of these safety features, I will be able to

safely make Biodiesel in my Appleseed.

The main extra features that I included in my Appleseed are timers and a digital thermometer. The timers are important because they not only help save time, but they also make the process more efficient and safer. The timer on the heating element means that it will shut off on its own, and that I don't have to worry about leaving it on. The back up timer that connects to both the heating element and the pump means that not only is there a fail safe for the heating element, but also that the pump will shut off on its own, saving even more time. That means that once I add the methoxide, I can walk away knowing that the pump will circulate and then shut itself off and allow the Biodiesel to settle. The other main extra feature, the digital thermometer also has several advantages. First, because it is digital, I will be able to check the temperature easily. The second important feature is that the thermometer I choose features a wireless alarm that beeps when it reaches the set temperature. That means that I don't have to monitor the oil while it heats, saving me time. It also means that since I will know right away when the oil reaches the correct temperature, I will be able to shut off the heating element sooner, saving electricity and making the process much more efficient. The extra features that I have included go a long way towards making my Appleseed the most efficient possible.

Although at the time I am writing this I have not yet made Biodiesel in my Appleseed, I will still address the process and how my Appleseed improves upon it. Having made numerous batches of Biodiesel in the Greengineering Appleseed, I know that the biggest issues are integrating the methoxide, turning off the heating element, and ensuring that the machine drains fully. In order to address the methoxide issue, I included a separate port to input the methoxide. This port can be isolated allowing for more control. I

installed two different timers to ensure that if the heating element is ever left on; it will eventually turn off on its own, preventing a dry fire. Finally, I installed multiple ball valves to help isolate the draining system. The ball valves allow me to control exactly where the Biodiesel goes, meaning that I am able to isolate the drain. Besides those improvements, I will follow the same basic process that I outlined in the Making Biodiesel in an Appleseed section. I also plan to try the 80/20 method. If I follow those procedures, then I should have no problem producing ASTM quality Biodiesel, the point of the Appleseed.

Overall, I believe that I was able to make the most efficient Appleseed possible with the resources at my disposal. With a budget of \$500.00, I was able to design and build a safe and energy efficient Appleseed that, while still remaining cost effective, is able to produce high quality Biodiesel. My Appleseed balances extra features for ease of operations with a simple design that almost anyone can build. My Appleseed offers numerous safety features, like GFCI protection and timers, to ensure that the Biodiesel that is produced is made safely and without risk of explosion. I think that my Appleseed has every feature necessary to make it one of the most efficient models that can be built.

Conclusion

While the question of which alternative energy source or sources will ultimately replace fossil fuels is far from settled, it is clear that Biodiesel will be in the conversation. Once the debate over Biodiesel begins, the topic of how best to make it is sure to come up, and while the Appleseed is not the answer for commercial production, it is the best option for the home brewer. An Appleseed is safe and affordable, yet still

produces fuel that meets the ASTM standards. Furthermore, because of the Open Source philosophy behind the design, Biodiesel enthusiasts are free to improve and customize the original design in search of the most efficient Appleseed. And while this paper has not settled the question of how to build the most efficient Appleseed, it certainly provides one solution --that the most efficient Biodiesel Reactor is one that combines ease of use, cost efficiency, and safety, yet still produces a high quality fuel without harming the environment-- to that important question, a question which will be settled in the near future.

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